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NAVORD REPORT

4112

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STATIC STABILITY AND MAGNUS CHARACTERISTICS OF A LOW-DRAG BOMB
AT LOW-SUBSONIC SPEEDS

FC

17 FEBRUARY 1956



U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

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Aeroballistic Research Report 306

STATIC STABILITY AND MAGNUS CHARACTERISTICS
OF A
LOW-DRAG BOMB AT LOW-SUBSONIC SPEEDS

Prepared by:

J. E. Greene

ABSTRACT: The Magnus and static stability characteristics of a 0.429 scale model of the U. S. Navy 1,000 pound low-drag bomb (EX-10) have been obtained from wind-tunnel tests at low-subsonic speeds for angles of attack up to 28 degrees. The variation in static aerodynamic coefficients due to roll orientation of the bomb and the effects due to the addition of external mounting lugs were also investigated. The tests were conducted by the Naval Ordnance Laboratory in the David Taylor Model Basin 8 x 10 foot subsonic wind tunnel.

The results of these tests indicate that the Magnus force and moment acting on the bomb are linear functions of the rotational speed but vary non-linearly with angle of attack. It is further shown that the Magnus coefficients are not appreciably affected by either the addition of mounting lugs or by changes in free-stream velocity. The variation of pitching and yawing moments due to fin-roll orientation is seen to be significant at large angles of attack. Depending upon the pitch and roll attitude of the bomb, the yawing moment may be as high as 40 percent of the corresponding pitching moment.

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

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NAVORD Report 4112

17 February 1956

This report presents the Magnus and static stability characteristics of a 0.429 scale model of the U. S. Navy 1,000 pound low-drag bomb at low-subsonic speeds. This work was done in the 8 x 10 foot subsonic wind tunnel at the David Taylor Model Basin, Carderock, Maryland, under task number A3d-453-1-56. Special instrumentation required to spin the model and measure dynamic and static forces and moments was furnished by the Naval Ordnance Laboratory.

W. W. WILBOURNE
Captain, USN
Commander

H. H. KURZWEG, Chief
Aeroballistic Research Department
By direction

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STATIC STABILITY AND MAGNUS CHARACTERISTICS
OF A
LOW-DRAG BOMB AT LOW-SUBSONIC SPEEDS

INTRODUCTION

1. The low-drag bomb family is a series of externally stowed bomb shapes stemming originally from the early Douglas External Store design. The family of bombs are all geometrically similar, but vary in weight from a minimum of 250 pounds to a maximum of 2,000 pounds.

2. In the early stages of development of the bomb, some difficulty was encountered with unstable flight performance after release from the aircraft. One contributing factor to the instability was thought to be due to a "coupling" or "resonance" effect between the roll and pitch frequency of the bomb. In an effort to overcome this "resonance" effect, the fins were canted (2 degrees) at an angle sufficient to produce an expected roll rate well above the pitch frequency. Under normal drop conditions, canting the fins proved sufficient to alleviate the problem of instability due to resonance effects. However, more recent tests at dive-bombing attitudes indicate that the bomb occasionally acquires a high-yaw oscillation upon release from the aircraft. The nature of this oscillation is not fully understood and apparently occurs only in a somewhat random fashion.

3. As a first step toward an adequate theory of motion for the bomb, and one which might be expected to help solve present or future problems of the type already experienced, the Bureau of Ordnance (ReW-4d) has initiated a program to determine the complete aerodynamic force-moment system acting on the bomb under all probable conditions of use.

4. As part of the first phase of the program, the Bureau of Ordnance directed the Naval Ordnance Laboratory to conduct low-speed tests of the 1,000 pound low-drag bomb. Accordingly, the Naval Ordnance Laboratory performed tests in the David Taylor Model Basin 8 x 10 foot low-subsonic wind tunnel at Carderock, Maryland, using a 0.429 scale model of the bomb. Magnus and static stability characteristics were obtained for model spin rates up to approximately 13 revolutions per second and angles of attack up to 28 degrees for free-stream velocities from 145 feet per second to 255 feet per second. In order to evaluate the effect of external mounting lugs and lug size on the aerodynamic characteristics of the bomb, the tests were performed using a model having no lugs and with lugs corresponding to the size used on the present 1,000 pound and 250 pound bombs.

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Symbols

A = maximum body cross-sectional area (sq. ft.)

C_N = normal force coefficient = N/qA

$C_{\theta c.g.}$ = pitching moment coefficient referred to the center of gravity = $M_{\theta c.g.}/qAd$

C_Y = side force coefficient = Y/qA

$C_{\psi c.g.}$ = yawing moment coefficient referred to the center of gravity = $M_{\psi c.g.}/qAd$

C_{Yp} = Magnus force coefficient (side force coefficient due to spin) = $\frac{\partial C_Y}{\partial p} \cdot \frac{2V}{d}$

$C_{\psi p}$ = Magnus moment coefficient (yawing moment coefficient due to spin) = $\frac{\partial C_{\psi c.g.}}{\partial p} \cdot \frac{2V}{d}$

d = maximum body diameter (ft.) = 1 (one) caliber

l = body length (ft.)

$M_{\theta c.g.}$ = pitching moment referred to the center of gravity (ft. - lbs.)

$M_{\psi c.g.}$ = yawing moment referred to the center of gravity (ft. - lbs.)

N = normal force (lbs.)

Y = side force (lbs.)

p = body rotational speed (radians/sec.) - positive when model is rotating clockwise as viewed from the base

q = dynamic pressure (lbs./sq.ft.)

Re = Reynolds number

V = free-stream velocity (ft./sec.)

μ = absolute coefficient of viscosity of air (lb.-sec./ft.sq.)

Symbols (continued)

ρ = air density (slugs/cu.ft.)

α = angle of attack (degrees)

ψ = angle of yaw (degrees)

Experimental Procedure

5. The model was mounted on a Naval Ordnance Laboratory four-component, internal strain-gage balance attached to a sector which provided for displacement in both pitch and yaw. Using the yaw movement only for initial alignment, the model was pitched in steps of 4 degrees through a total angle range of -12 degrees to +28 degrees.

6. To provide spin, a DC motor was attached to the forward end of the balance beam and geared to the cylindrical center section of the model. Maximum rotational speed was limited by the gearing arrangement of the motor to 1,000 RPM. A tachometer, mounted directly behind the motor section, was used to measure the model spin rate in revolutions per minute on a Berkeley EPUT counter.

7. A sketch of the model showing the major dimensions of the bomb and the mounting lugs is presented in Figure 2. The model had a maximum diameter of 6 inches and an overall length of approximately 49 inches. Model construction was entirely of aluminum with provision at the base of the model for sting mounting.

8. The output signals of the strain-gages measuring Magnus forces and moments were suitably amplified and supplied to the pen drive on a two-channel, Leeds and Northrup, Speed-O-Max recorder. By modifying the conventional time drive of the recorder chart to include a servo-motor driven by the model tachometer signal, it was possible to position the chart as a function of the model rotational speed and thus obtain a "trace" or record of the Magnus moment about each of the gage sections as a function of model spin rate for each angle of attack. Due to the inability of the recorder chart to follow a tachometer signal corresponding to approximately 50 revolutions per minute or less, it was necessary to extrapolate the Magnus moment "trace" to zero rotational speed in order to obtain an initial slope through zero.

9. Since there was no measurable effect of model spin on the normal forces or pitching moments, the static components were "read out" on a DC amplifier meter at each angle of attack and reduced to coefficient form using the conventional pre-test calibration data.

Data Reduction

10. The Magnus moment "traces" obtained on the recorder chart were found to be linear with model rotational speed. It was sufficient, therefore, to use only the difference in the Magnus moment between zero RPM and 800 RPM. From this value, the Magnus coefficients, C_{Y_p} and C_{ψ_p} , were obtained in non-dimensional form by the relations:

$$C_{Y_p} = \frac{\partial Y}{\partial p} \cdot \frac{2V}{d} \cdot \frac{1}{qA}$$
$$C_{\psi_p} = \frac{\partial M_{\psi c.g.}}{\partial p} \cdot \frac{2V}{d^2} \cdot \frac{1}{qA}$$

Normal force, pitching moment, side force, and yawing moment were reduced to the conventional coefficient form as shown in the section under Symbols.

11. With the assumption that the errors in the measurements would follow a "normal probability curve," the probable error, of a single observation at a given angle of attack, was determined from a few repeat runs to be the following values:

$$\Delta C_{\psi_p} = \pm 0.40$$

$$\Delta C_{Y_p} = \pm 0.16$$

$$\Delta(C_N, C_Y) = \pm 0.05$$

$$\Delta(C_{\theta c.g.}, C_{\psi c.g.}) = \pm 0.04$$

It should be noted that the curves showing normal force, pitching moment, side force, and yawing moment coefficients have been shifted parallel to the coefficient axes in order that the coefficients show zero value at zero angle of attack. The displacement of the coefficient curves from the axes origins was attributed to initial misalignment of the model with the tunnel centerline.

Discussion

12. The effect of adding mounting lugs and changing the lug size on the Magnus characteristics of the bomb at $V = 255$ feet per second is shown in Figure 3. Although a small effect appears to be present, it is evident that the lugs do not appreciably alter the Magnus force

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and moment magnitudes and variations with angle of attack. It should be noted that, within the test range of angles of attack, both the Magnus force and moment are linearly dependent upon the rate of spin, at least up to the maximum test-spin rate of approximately 13 revolutions per second. Up to 14 degrees angle of attack, the magnitude of the forces and moments at maximum spin are roughly 10 percent or less of the corresponding normal forces and pitching moments. At higher angles, however, the Magnus contribution approaches values as high as 25 percent of the normal force and 40 percent of the corresponding pitching moment.

13. Figure 3 also shows an average curve of the Magnus center of pressure variation with angle of attack for all three configurations (BF, BFL-1, and BFL-2). Due to the slight differences in Magnus forces and moments between configurations, the values of Magnus centers of pressure scatter, in a more or less random fashion, about the curve with a mean scatter of approximately ± 0.14 calibers. As can be seen, the center of pressure is fairly constant up to approximately 12 degrees, thereafter, moving toward the base of the bomb at larger angles. Up to 28 degrees angle of attack, the total Magnus center of pressure travel does not exceed 13 percent of the overall bomb length.

14. Figure 4 shows the effect of small variations in free-stream velocity on the Magnus characteristics of the bomb with mounting lugs scaled to the 1,000 pound bomb size (BFL-1). Here again, the Magnus characteristics are similar to those shown in Figure 3. There is no appreciable effect of velocity on the coefficients except at $V = 145$ feet per second where a decrease in both the Magnus force and moment coefficients is to be noted. This difference may be attributable to the variation of free-stream Reynolds number (Table I) rather than the variation in velocity (see reference b). The variation in Magnus center of pressure presented in Figure 4 is shown as a band which encloses the spread due to differences in the coefficients at the various test velocities.

15. Figures 5 and 6 show the stability characteristics of the bomb as determined from measurements made with the model spinning (50 to 800 RPM). Figure 5 presents the variation of normal force, pitching moment, and normal force center of pressure for configurations BF, BFL-1, and BFL-2 at $V = 255$ feet per second and angles of attack up to 28 degrees. In this case, the test results show that the small configurational changes produced no measurable differences in the coefficients. The results further show that the normal force and pitching moment are insensitive to spin, at least for spin rates from approximately 50 to 800 RPM, hence, only one representative curve is shown for the conditions of varying spin and configurational modifications. Figure 6 shows the effect of varying free-stream velocity on the stability coefficients of configuration BFL-1. As can be seen, only the pitching moment coefficient exhibited any variation due to change in tunnel air speed. This variation is depicted as a band which encompasses the spread in pitching moment coefficients obtained at the various test

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velocities (Table I). The normal force center of pressure remains fairly constant at roughly 18 percent of the body length behind the center of gravity. There is, however, a small forward shift at angles of attack below approximately 12 degrees. It is interesting to note that the Magnus and normal force centers of pressure approximately coincide at angles less than 14 degrees.

16. The effect of fin-roll orientation on the normal force, pitching moment, side force, and yawing moment is illustrated in Figures 7, 8, and 9. The zero roll position (ϕ = zero degree) is considered to be the position in which the bomb fins would make an angle of 45 degrees with a plane containing the free-stream wind vector. From Figures 7 through 9, it can be seen that the effect of roll position on normal force and pitching moment is small for angles of attack below approximately 8 degrees. At larger angles, however, a change in roll position of 48 degrees (+3 degrees to -45 degrees) results in as much as an 80 percent increase in the pitching moment and up to a 25 percent increase in the normal force. The effect of roll position on the normal force center of pressure is negligible at angles of attack below 8 degrees. At the larger angles, however, a rearward center of pressure shift of roughly one-half caliber occurs as the roll angle is changed from ϕ = +3 degrees to ϕ = -45 degrees. Effects due to mounting lugs appear to be small and somewhat inconsistent at the various test roll angles.

17. Figures 7, 8, and 9 also show the variation of side force and yawing moment coefficients with angle of attack for various roll positions. Below approximately 8 degrees side forces and moments are negligible. At larger angles, however, these coefficients are seen to be markedly non-linear for given roll positions.

18. The addition of lugs to the bomb has a noticeable effect on the side force and yawing moment characteristics. These effects are evidenced mainly at angles of attack above 16 degrees and for roll angles between ϕ = -10 degrees and ϕ = -45 degrees. In general, the magnitude of both the side force and yawing moment in this region is increased. For the lugs-on configurations and roll angle of ϕ = -45 degrees, the direction of the side force is reversed, resulting in a change from negative to positive yawing moments for that roll position. It appears that for a given angle of attack, as the bomb is rolled from a position of least restoring moment (ϕ = +3 degrees) to a position of greatest restoring moment (ϕ = -45 degrees) the presence and size of the lugs affects the side forces and moments more strongly.

CONCLUSIONS

19. In summary, the results presented in this report show that the Magnus force and moment coefficients of the bomb are linearly dependent upon the bomb rotational speed and may, depending upon the

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angle of attack and spin rate, approach values as high as 25 percent of the corresponding normal force and 40 percent of the corresponding pitching moment. The Magnus coefficients are seen to be relatively insensitive to the addition of mounting lugs or to small changes in the free-stream velocity. The results also show the bomb to be statically stable at all angles of attack. In addition, normal forces and pitching moments are seen to be little affected by spin in the range 50 to 800 RPM. It is also seen that static normal forces and restoring moments vary appreciably with fin-roll orientation, increasing as much as 80 percent in the restoring moment and up to 25 percent in the normal force for roll positions from $\phi = +3$ to $\phi = -45$ degrees. Static side forces and moments are seen to be highly non-linear with variation of angle of attack and to be adversely affected by the presence of lugs. The addition of lugs causes the side moment to increase appreciably for given angles above approximately 16 degrees and for roll angles from $\phi = -10$ degrees to $\phi = -45$ degrees.

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References

- (a) Wright, John "Wind-Tunnel Investigation of a 0.429 Scale Model Low-Drag Bomb" DTMB Report C-717 Aero Data, Report 31, June 1955 (Conf)
- (b) Fagin, S., Sparks, W. F., Greene, J. E., "Summary of the NOL Investigations to Date of the Aerodynamic Forces and Moments, Including the Magnus Forces and Moments, Acting on the 6" Test Vehicle and the 12.75" AS Rocket" NavOrd Report 3666 March 1954 (Conf)

Table I

Test Conditions

Free-Stream Velocity (feet per second)	Dynamic Pressure (lbs/sq. ft.)	Re x 10 ⁻⁶ (based on total length of model)
255	75.0	6.3
231	62.5	5.8
204	50.0	5.3
178	37.5	4.5
145	25.0	3.7

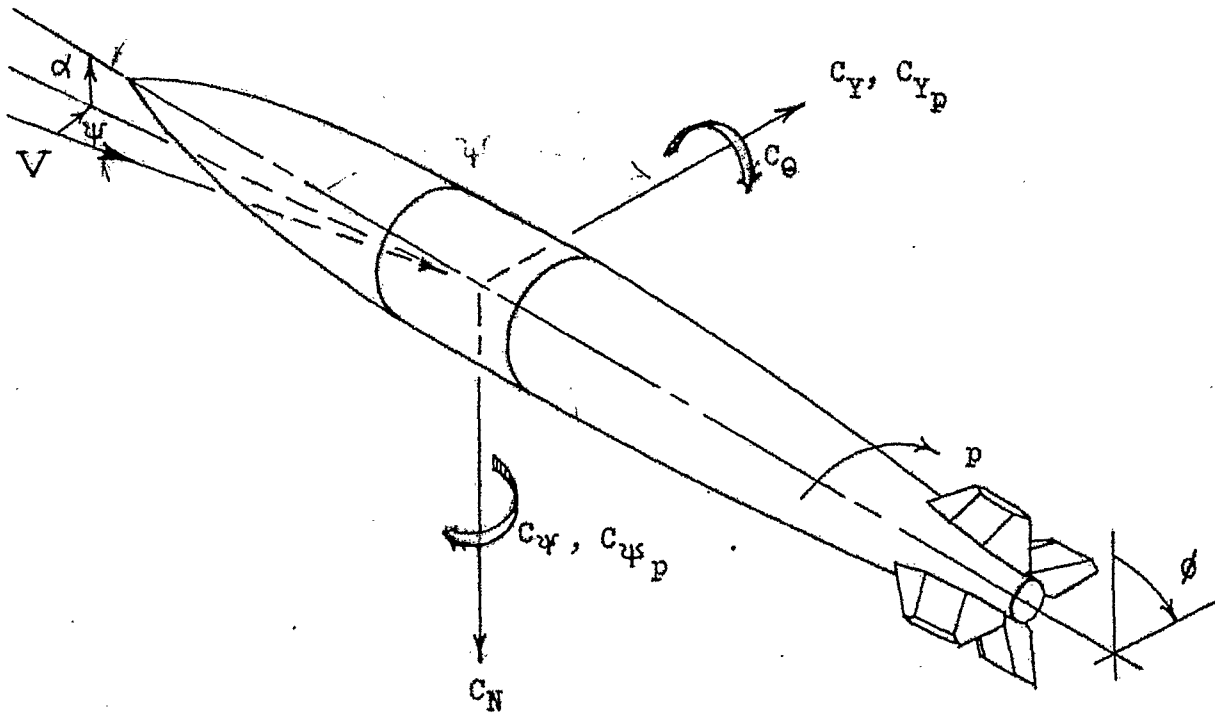
Configuration Designation

BF (Body-Fin) - No mounting lugs

BFL-1 (Body-Fin-Lugs) - Bomb with lugs scaled to size used on
1,000 pound bomb

BFL-2 (Body-Fin-Lugs) - Bomb with lugs scaled to size used on
250 pound bomb

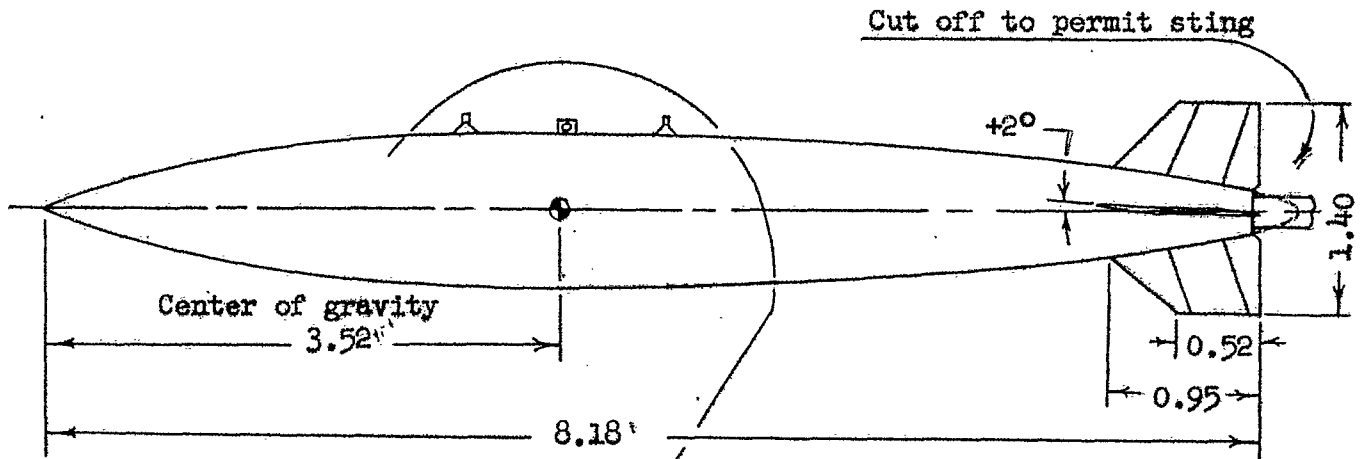
Coordinate Axes and Sign Convention



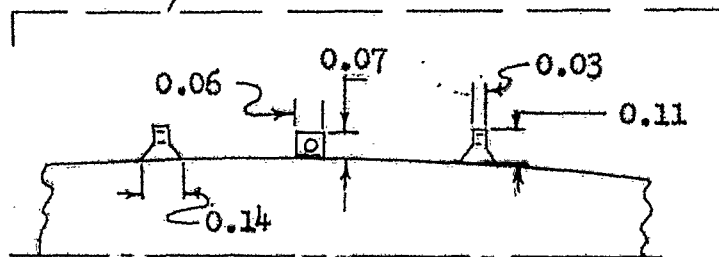
Positive direction of angular displacement, spin, and coefficients is indicated by the above diagram

Fig. 1

Sketch of 0.429 Scale Model of the
1000 lb. Low-Drag Bomb



All dimensions in terms of maximum diameter -d
d = 6 inches



Lugs scaled to 250 lb. bomb size = 1.56 x dimensions shown.

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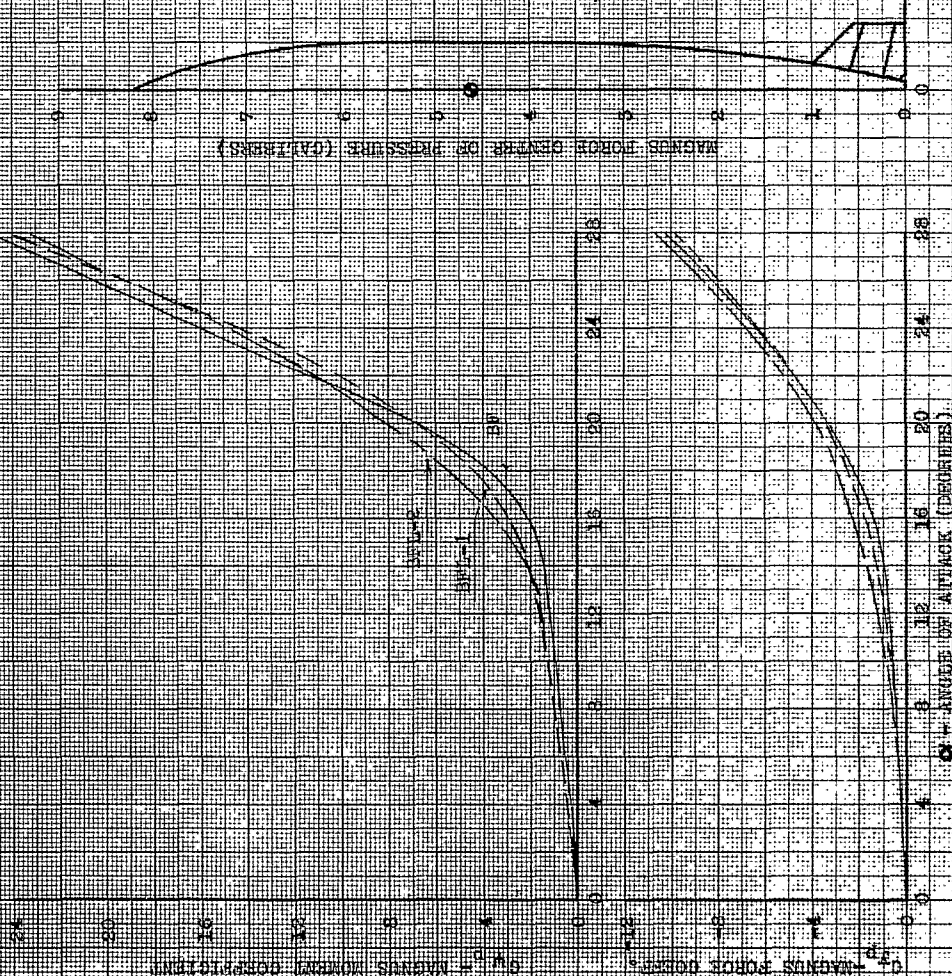
NAVJAG REPORT 418

VARIATION OF MAGNETIC FORCE, MAGNETIC MOMENT AND
COEFFICIENT OF RESISTANCE WITH ANGLE OF ATTACK

$D = 0.400$ RPM

$V = 235$ Knot/sec.

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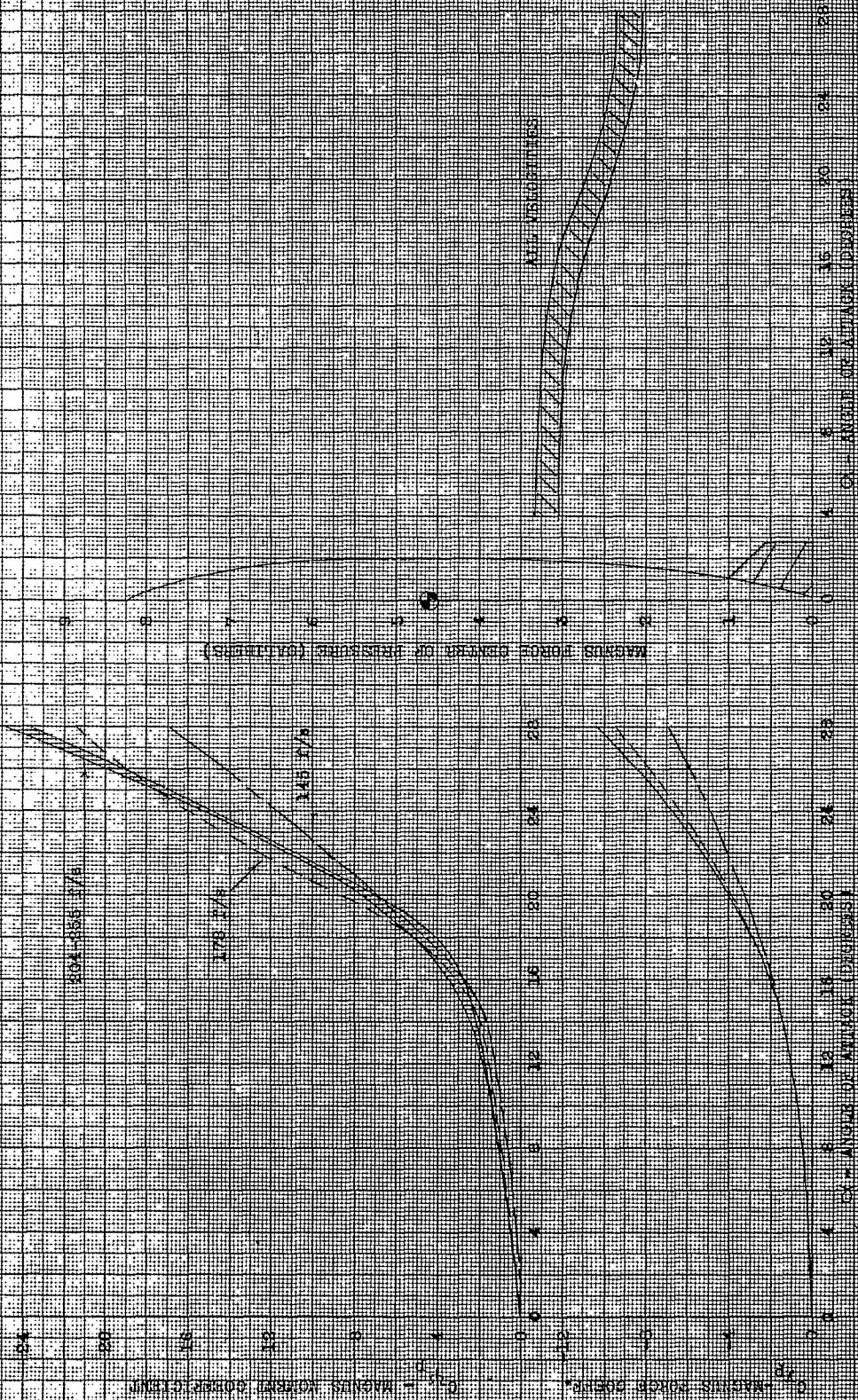
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500-1

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EFFECT OF VELOCITY ON THE MAGNETIC
CHARACTERISTICS OF THE 1,300 LB. BOMB WITH
SCALED LOGS

P = 0.800 RFR
CONFIGURATION EPL-1



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FIGURE 4

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VARIATION OF NORMAL FORCE, FINISH LINE MOMENT AND
CENTER OF PRESSURE WITH ANGLE OF ATTACK FOR
VARYING SPIN RATES

$\rho = 50-800 \text{ RPM}$

$V = 255 \text{ feet/sec}$

CONF. ST. BTI-1, BTI-2

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FIELD AND INDOOR

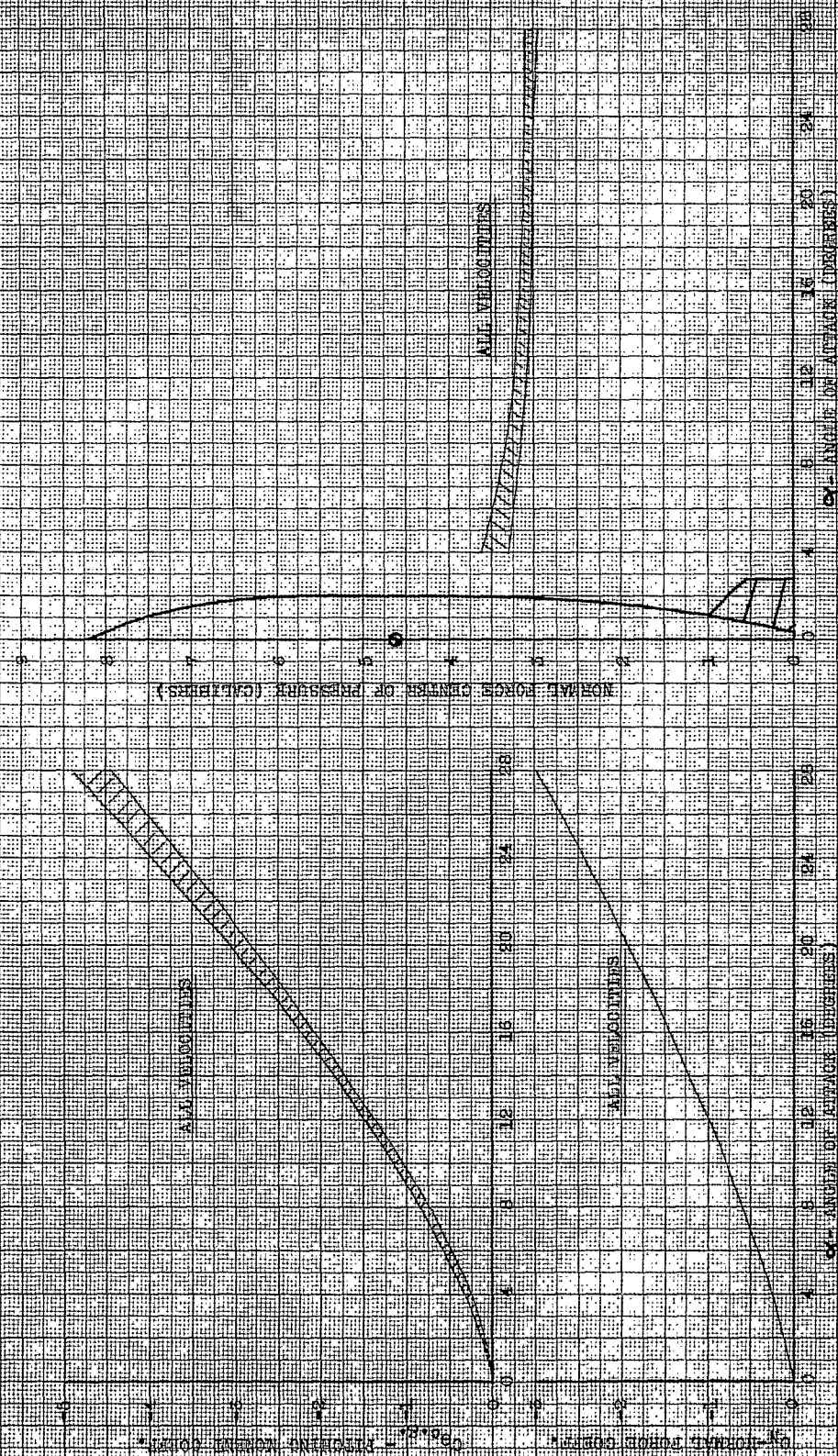
NEW YORK REPORT 4112

EFFECT OF VELOCITY ON THE STATIC STABILITY
CHARACTERISTICS OF THE 1,000 LB. BOMB WITH
SCARDED LUGS

$\omega = 50-800$ R.P.M

$$v = 1.45 \text{ p/s to } 2.55 \text{ p/s}$$

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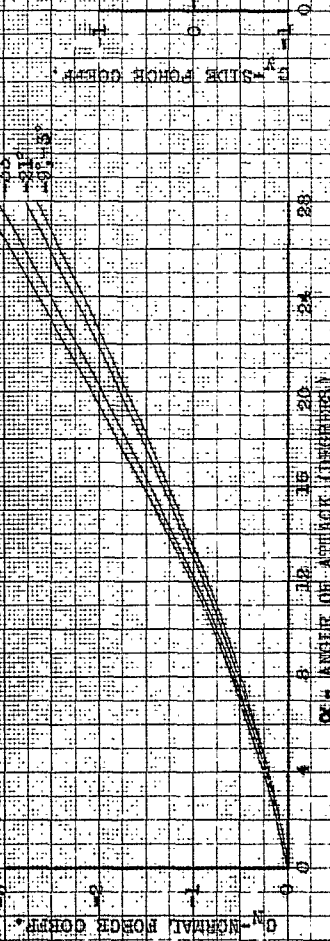
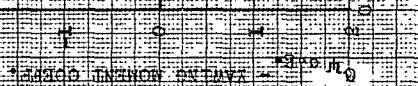
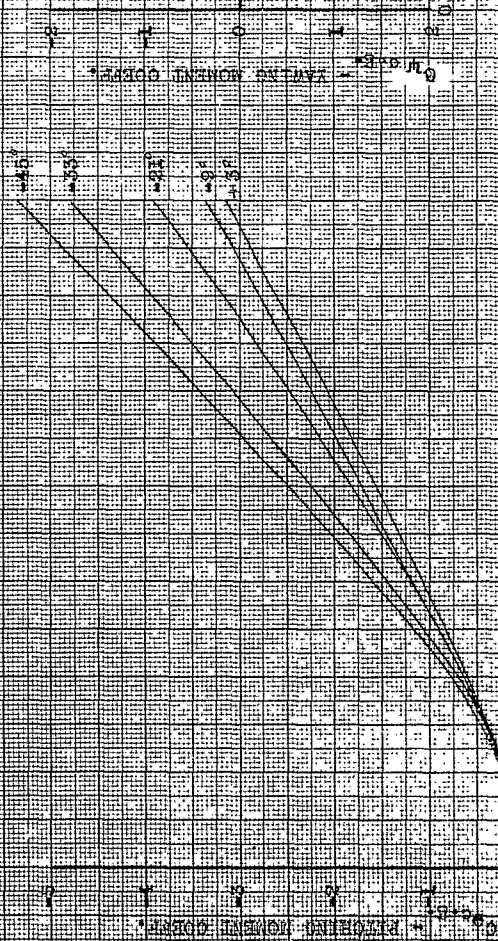
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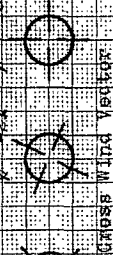
SCOPE OF THIS ORIENTATION ON NORMAL FORCE,
ROLLING MOMENT, SLIDE FORCE, AND TURNING MOMENT

V = 235 feet per second

CONFIGURATION BFW-1



Roll position angles from base
 $\phi = 0^\circ$, $\phi = 30^\circ$, $\phi = 60^\circ$, $\phi = 90^\circ$



α - ANGLE OF ATTACK (DEGREES)

α - ANGLE OF ATTACK (DEGREES)

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EFFECT OF FIN ORIENTATION ON NORMAL FORCE,
PITCHING MOMENT, SIDE FORCE, AND YAWING MOMENT

$V = 255$ feet per second
CONFIGURATION BP

-45°

-33°

-21°

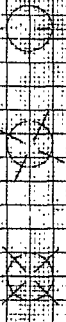
-9°

-3°

$C_{D,N}$ - NORMAL FORCE COEFF.
 $C_{M,P}$ - PITCHING MOMENT COEFF.

$C_{D,S}$ - SIDE FORCE COEFF.
 $C_{M,Y}$ - YAWING MOMENT COEFF.

Roll position as seen from base
 $\phi = 15^\circ$ $\phi = 21^\circ$ $\phi = 45^\circ$



CROSS WIND VECTOR

-45°
-33°
-21°
-9°
-3°

α - ANGLE OF ATTACK (DEGREES)

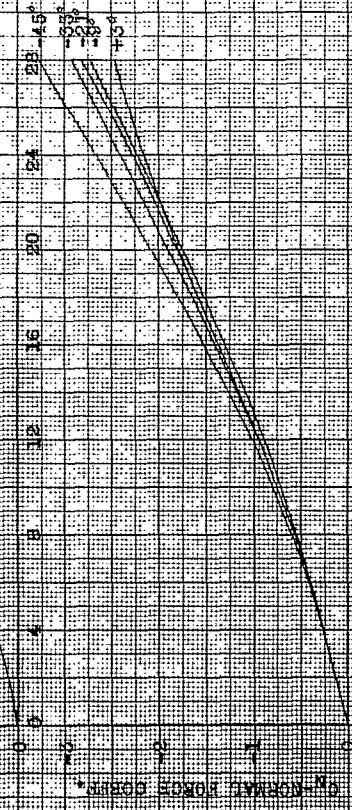
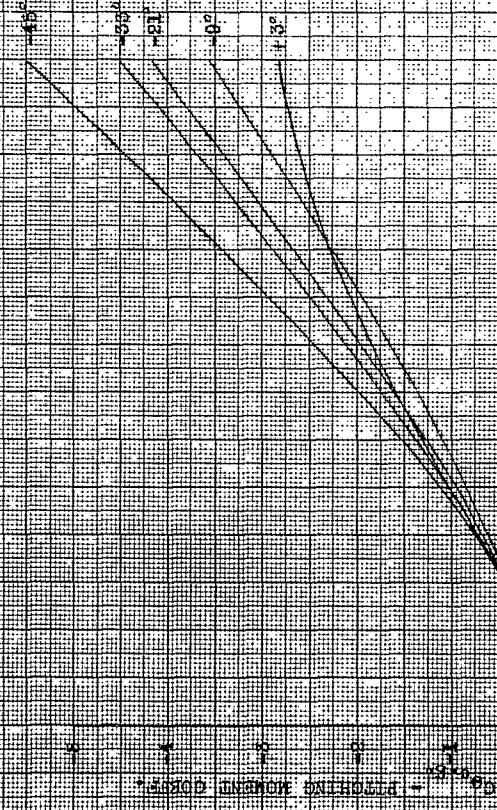
ϕ - ANGLE OF ROLL (DEGREES)

FIGURE 2

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EFFECT OF FIN ORIENTATION ON NORMAL FORCE,
PITCHING MOMENT, SIDE FORCE, AND YAWING MOMENT
V = 255 Feet per second
CONFIGURATION 341-2



PITCHING MOMENT COEFF.

NORMAL FORCE COEFF.

YAWING MOMENT COEFF.

SIDE FORCE COEFF.

Roll position as seen from base
 $\phi = 3^\circ$ $\phi = 21^\circ$ $\phi = 45^\circ$

Gross Wind Vector

α - Angle of Attack (Degrees)

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